THE PROGRESS OF FOREST PATHOLOGY

FROM

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By Carl Hartley, J. S. Boyce, and others [1] in the Division of Forest Pathology, Bureau of Plant Industry

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INTRODUCTION

Among the diseases are included not only those caused by fungi, bacteria, mistletoes, and other types of parasitic plants, but also the unhealthy conditions resulting from such causes as frost, excessive heat, and poisonous gases. Some of the effects of drought, wind, fire, and mechanical injuries are sufficiently like those of parasites or have such an influence on the course of the parasitic diseases that for practical purposes they are also classed among the diseases. Insect injury is considered elsewhere, though there are some cases in which the insects and plant parasites work in such close partnership that they cannot be entirely separated.

Diseases affect forest productiveness in three ways—by killing trees, by slowing down tree growth, and by degrading or destroying the wood after it is grown. Reliable loss figures are available for only a single kind of damage, i.e., decay of wood that has already grown, and even for decay they are available for only a few of our forest-tree species. Diseases sometimes lower the value of the forest for recreational use by rendering it unsightly and occasionally hurt its effectiveness in watershed protection. Direct control measures are being applied on a considerable scale only in forest nurseries and against blister rust in the white-pine forests.

FOREST DETERIORATION BY NATIVE DISEASES

DISEASES AFFECTING NURSERIES

There are a number of diseases that have caused serious loss in nursery stock in the past. The obvious result has been unnecessarily high cost of planting stock at the nurseries where disease has been most prevalent. Even a very moderate increase in plantation cost

[1] Especially S. B. Detwiler, E. P. Meinecke, W. W. Wagener, R. K. Beattie, and Lake S. Gill.

after interest charges have accumulated on it for half a century may make the difference between profit and loss on the plantation. At many nurseries there are occasional disease epidemics which practically destroy entire blocks of beds and introduce a troublesome uncertainty into the raising of planting stock and in planting programs. Because this uncertainty feature is one of the most serious effects of nursery diseases, and since its effect cannot be expressed in dollars and cents, no quantitative estimate of the total loss due to disease can be made. Another consequence of diseases in the nursery which is hard to evaluate, but which may prove more important than all others, is the introduction of disease into new plantations on the planting stock.

Some of the heaviest losses have been due to nonparasitic diseases, particularly drought, excessive heat of the soil surface, frost and winterkilling, and from unwise use of mulches or fertilizers. All of these are reasonably easy to prevent when recognized, and prove troublesome chiefly because they are often confused with parasitic diseases. Education and increasing experience of the nurserymen have already resulted in reducing loss from these sources, and they should not be serious in the future.

Diseases due to parasitic fungi include the "damping off" of very young seedlings, root rot of older stock, needle diseases, molds that work under snow cover, and the stem rusts of pines. Damping off has been found to yield to inexpensive methods of soil disinfection or acidification in most places, needle diseases and fungi under snow can be prevented by spraying and supplementary practices, and rust infections can be minimized by eliminating infection sources from the vicinity. Root rots are the only major group of nursery diseases for which no reasonably effective control methods are known. A number of alternative treatments are available for trial on nursery diseases which would be too expensive for use in field plantations or natural reproduction. Some diseases will probably always be found too difficult or too expensive to control at all nurseries or on all tree species; but the nursery industry requires relatively little ground, and at the worst it can hunt for sites on which a susceptible species is found least subject to infection. The development of a new treatment or the finding of the best nursery site for raising a particular species usually requires years of experimentation, but if adequate research is maintained, reforestation plans need not be retarded for fear of diseases of conifers in the nurseries, at least so far as native diseases are concerned. With hardwoods there has been less experience, but no disease is expected for which a few years of investigation would not develop satisfactory control on the more favorable nursery sites.

DISEASES AFFECTING PLANTATIONS

Diseases in plantations have been less studied than in nurseries. Plantations, if on properly chosen sites, ordinarily suffer less from disease during their first few years than do nurseries. There are, however, exceptions to this rule among the diseases already studied. For example, the brown-spot needle disease in the longleaf pine of the Gulf States becomes important very early, even in well-placed plantations. In much of the longleaf region this disease attacks the trees during the first few years after planting and so weakens them

that they require several more years to start height growth than do the uninfected trees, and many of them die. Spraying with fungicides during the first two or three years, and in some cases the use of fire in preparing planting sites, are expected on the basis of studies now in progress to minimize the losses from this disease at a cost that would be more than counterbalanced by the decreased length of time required for the establishment of the plantation; but with the best success that can be expected this disease will continue to be something of a handicap in the reforestation of the large areas of denuded longleaf land in the South. Another disease of young plantations which can be only partially avoided by any methods at present known is the Phacidium blight of spruce and fir in the Northeast, which destroys trees that are small enough to be buried in snow.

Where sites are obviously not properly adapted to the species or are chosen without reference to disease hazards, plantations may be badly injured by disease in early life. For example, Douglas fir is seriously damaged if planted where late spring frosts are frequent. Conifer plantations should not be located on land where certain parasites are present in quantity unless it first proves practicable to destroy the sources of infection. This rule holds for the dwarf mistletoes of pine and Douglas fir in the West, and for stem rusts that easily attack ponderosa pine, loblolly pine, and other species of both East and West. In reforesting sites in parts of the industrial region of the Northeast, species particularly susceptible to injury or growth reduction by smoke or sulphur dioxide should not be employed.

In general plantations continue healthy till they reach the sapling or pole stage, but some of them begin to deteriorate after that time. Even trees that are not overcrowded may stagnate, or become deformed, or perhaps die. Such failures in plantations that had started well are little understood. Part of them appear to be due to root diseases, which are enabled to attack the trees as the result of too deep planting, unfavorable soil, the use of pure stands of a single species, or the use of stock grown from seed collected in habitats different from that in which the planting is made. All types of parasitic disease, but especially the root rots, are favored by growing large numbers of the same species of plant in pure stand. Pure stands are relatively rare in nature, and their use in plantations undoubtedly accounts for some of the disease liability. No one knows enough about soil factors to be certain what sites will grow healthy plantations of any particular species, and most plantations are of necessity placed on old fields where soil conditions are no longer normal for forest growth. There is particular need to correlate soil studies with studies of plantation diseases. While root troubles are difficult and expensive subjects for investigation, it is highly desirable that unsatisfactory plantations should be subjected to intensive root study by pathologists.

Most of our forest species have practically all of their finer absorbing roots infected with mycorrhiza fungi, so that their absorption of moisture and minerals from the soil must be through layers of symbiotic fungi. Some students of the mycorrhiza have regarded them as beneficial to the tree, while others consider them harmful. There is every reason to believe that some of the species of mycorrhiza fungi are harmful to particular tree species or under some kinds of

conditions, and that some of the plantation difficulties may be due to them. The subject has been found by early investigators to be one of extraordinary difficulty. Systematic studies have been undertaken recently in this country, and it is hoped that some of the points in question may be cleared up. There seems to be no hope of preventing the development of mycorrhiza, even if it were proven desirable to do so. There is, however, a possibility that when our knowledge of these fungus-root structures becomes more adequate we can influence the success of a plantation by seeing that the right species of mycorrhiza fungi get possession of its roots before the trees leave the nursery.

In this connection special mention should be made of the disease situation resulting from the use of exotic tree species in forest plantations. A considerable number of foreign trees are being tried in a small way by our forest planters, and Scotch pine and Norway spruce are grown to a considerable extent in the Northeast. Exotics can be advantageously planted for special local wants; for example, to produce hardwoods on the Pacific coast, to produce chemicals, as tannin or heptane, or to supply timber that is more resistant to termites and decay than the local species. As native species are eliminated by introduced diseases or insects, we will have increased need for trial of exotics. One case of introduction of exotics to replace a lost species has already appeared in the Asiatic chestnut species which are being introduced in quantity in the hope of getting a satisfactory replacement of the American chestnut; these, although resistant to chestnut blight, are already being attacked by several of our native fungi. It is true that in migrating to a new home, a tree species sometimes escapes from parasites which have reduced its usefulness in its native range, and makes better growth in the new habitat than it did in the country of origin; but most exotics are not so fortunate. An introduced tree is very likely to find in our rich fungous flora at least one parasite to which it will lack resistance. Such a fungus may be rare or geographically limited at first, and cause no serious trouble to isolated test plantings; but if the exotic tree becomes widely used, the troublesome fungus can multiply and extend, slowly at first and with gradually increasing speed, till at the end of one or two generations of extensive use of the new tree its early promise may entirely disappear. This is exactly what happened to our American white pine when it was used in Europe. It was adopted by British and Continental tree planters with great initial success. Rapid growth and high quality in early trials resulted in extensive planting. Now, after half a century of additional experience, white pine is being abandoned over a large part of the countries in which it was once popular. The ultimate failure is entirely due to a rust fungus, previously rare in Europe, which found a congenial host in the introduced species and gradually became more widespread and abundant till it became a controlling factor. Scotch pine, the exotic which we have most employed in the United States, and which seemed for the first few decades to be quite free from enemies, is now being attacked to an alarming extent in Pennsylvania, New York, and New Jersey by at least three diseases, the sweetfern rust, the Woodgate rust, and the other of yet undetermined cause.

As has been pointed out, much of the pathological condition of plantings of native species in the past appears to be due to the use of

seed from distant sources and different climates, rendering the native tree species essentially an exotic in the locality where it is planted. For example, Norway pine from northern Minnesota seed cannot be expected to be normally resistant to parasites if it is planted in the Middle Atlantic States. A native tree may even be planted entirely outside of the natural range of the species; for example, northern white pine is planted in Ohio and Indiana where despite good initial growth plantations have suffered severe losses from an obscure wilt disease. This practice of use of seed from a distance is always likely to be followed to a certain extent, because of the difficulties in obtaining seed of some species just when and where it is wanted, but is fortunately becoming less common as the foresters recognize its danger. Another factor must, however, be considered in estimates of disease susceptibility of future plantations. Forest geneticists are beginning to select particularly desirable types from our timber species and even to breed them. In poplars planted for pulp, vegetatively propagated varieties will probably be in common use in the not distant future. This means that strains of fungi very specially adapted to the particular strain of the tree species that is being used will have an unprecedented opportunity to spread. In a promising attempt begun some years ago by a paper company to utilize fertile overflow land in Ohio by growing the so-called "Norway poplar", a uniform fast-growing variety, the tree had to be abandoned because of a branch canker disease which overran the plantings after they had been under way for a period long enough to let the specialized parasite multiply. While the forest-tree breeder will select his types from those that appear resistant to the more important diseases, it will be very difficult to insure resistance to all the species and strains of fungi concerned, and this will be particularly true for the soil-inhabiting fungi. We have some reason to fear that progress in forest genetics, if or where it goes far enough to give us planted forests of selected strains, may conceivably put our forest plantations into somewhat the same condition of disease susceptibility that we already see in our orchards. This is particularly likely unless study of diseases and development of methods for testing resistance proceed more rapidly for the species to which the geneticists give their attention. On the whole, more trouble is expected from disease in plantations than in nurseries or in young stands arising by natural regeneration. Because of its cost, there is little chance for direct control of diseases in field plantings. This means that we must not only learn to distinguish the different diseases, but particularly for the root diseases we must know their means of spread and their relation to soil conditions, stand density, species mixture, kind of mycorrhiza, and every other factor through which the activity of the parasite or the resistance of the host may be indirectly influenced either in choosing plantation sites or in making and managing the plantations. Unless the present information on these subjects is rapidly increased, it is to be expected that there will continue to be disappointing results in some of the new plantations due to injury by native disease organisms.

DISEASES AFFECTING IMMATURE FORESTS

Forest stands throughout their life are subject to unfavorable influences which reduce their productive capacity, either by a reduction in the rate of growth or by adverse changes in the density of

stocking. Fully stocked stands are exceptions rather than the rule in this country. For example, in the Pacific Northwest the average stand of immature Douglas fir is stocked from only 82 to 83 percent of board-foot capacity, while for other species in other regions the percentage of understocking seems generally higher. Although the character of this loss is apparent, its exact evaluation is difficult, and it is particularly hard to accurately gage the effect of each of the causal factors of this understocking when more than one is operative, as is usually the case. However, parasitic fungi and dwarf mistletoes of conifers play an important part in reducing yield, both by killing trees, thus causing understocking, and by lessening growth rate, thus requiring a longer time to produce a given quantity of timber. Diseases of the foliage, while rarely causing the death of enough trees to affect stocking, by killing many leaves do interfere with food production to such an extent that rate of growth is reduced. A particularly notable case is the brown-spot needle disease of longleaf pine already mentioned in connection with plantations, which so weakens young trees in natural reproduction in parts of the South that it not only adds a number of years to the time required to grow merchantable timber but on the poorer sites it may kill so many seedlings as to entirely prevent the development of a properly stocked stand. Root rots and stem-inhabiting fungi, particularly rusts, also kill many young trees. These parasites rarely become suddenly epidemic in such a way as to kill trees over extensive areas in a short time; they more commonly take a steady annual toll from infected stands. Here again if the productive capacity of the stand is not reduced, the losses are of no consequence, but if enough trees are killed either to cause understocking or in addition in a mixed stand partial elimination of the more valuable species, then significant damage results.

The most serious diseases reducing growth rate and also killing trees outright are those caused by dwarf mistletoes of conifers. These dwarf mistletoes are very different from the holiday mistletoe known in the East; they have no leaves and are without any sentimental or esthetic value. In the West there are few conifers free from their attack. The valuable stands of ponderosa pine in particular suffer severely. Over extensive areas throughout the range of this pine many trees are so deformed as to be worthless, some are killed, and many more are infected sufficiently so that their rate of growth is considerably lessened. A normally stocked stand of 40-to-50-year-old ponderosa pine in northern California, moderately infected with dwarf mistletoe, was found to have one third of the trees infected and 14 percent ruined by stem infections. On another area where the attack was heavier every tree was infected and over 80 percent were ruined by stem infections. In northern Arizona the average volume increment over a 5-year period was found to be 4.53 cubic feet for healthy trees and 2.23 cubic feet for heavily infected trees. Stands of ponderosa pine over limited areas are so severely attacked that they are worthless for lumber.

The aggregate loss from diseases in immature stands destined for timber production is high and probably approaches or exceeds the losses caused by decay in mature stands. In the future, as mature stands are even more depleted, the damage caused by these diseases in immature stands will increase greatly in relative importance.

Native diseases of immature stands must be largely controlled by measures applied when the timber is cut. It is axiomatic that direct

eradication of these diseases by a special control operation is rarely warranted, since they do not threaten the perpetuation of any commercial species. When timber is finally cut all diseased trees should be removed, leaving only healthy individuals for seed trees or for the nucleus of the next cut. This will reduce the amount of disease in the reproduction, and where early thinnings are practicable, diseased trees can be removed while they are still small, leaving the final crop composed of healthy individuals. In certain managed hardwood stands in southern Connecticut, where there is an active demand for fuel wood, it is now the practice to thin out the undesirable trees early in the life of the stand, with particular emphasis placed on the removal of oaks suffering from Strumella canker.

DISEASES AFFECTING MERCHANTABLE FORESTS

Native killing diseases affecting merchantable forests do not usually cause spectacular damage, but in the aggregate these losses are of consequence, since almost every tree killed results in a corresponding reduction in volume of the stand. Furthermore, killed trees usually occur as scattered individuals or groups so that it is economically impossible to salvage them. Parasitic fungi and mistletoes take a steady annual toll from mature stands, and occasionally unfavorable weather conditions cause heavy losses. Following a drouth period culminating in 1925, mature trees died so extensively in the bottomland hardwood region of parts of the South, that the loss was believed to equal a normal year's cut by the mills of the region. Occasionally groups of mature trees are killed by lightning. While little can be done to prevent killing of mature trees by adverse climatic conditions, it will ultimately be possible to reduce losses caused by fungi and dwarf mistletoes, through the elimination of infected trees when the stand is cut so that the new, immature stand will not be exposed to infection from old, diseased individuals.

The great loss from fungus action in merchantable stands is in the destruction of heartwood of living trees by decay fungi. In Douglas fir, the timber species on which the most extensive data are available, this loss amounts to 17 percent. Since Douglas fir comprises nearly one third of the remaining saw timber of the entire United States, the cull in this species alone means that more than 5 percent of our apparent timber supply is worthless. In other species of which the remaining stand is much less, the percentage loss through decay is even higher. In the mixed coniferous forests of northern Idaho, western hemlock is so badly decayed as to be largely unmerchantable. Throughout much of the range of white fir, cull from decay is so heavy as to amount to complete destruction of the merchantable stand. In the Adirondack Region of New York, loss from decay in beech is so high as to make this species of doubtful value. The same species is so defective in the bottomland hardwoods of Louisiana that it is frequent practice in logging operations to leave all of the beech trees standing. It is figured in the northern Rocky Mountain region that defect, largely decay, increases the unit cost of timber production in nearly the same ratio as the occurrence of the defect itself. In addition a much larger ratio of low-grade lumber is produced from a defective stand than from a sound one of similar growth rate. These lower grades are difficult to sell even during a high

market, and nearly impossible to dispose of when lumber prices are low. Decay in the forest may thus result in over cutting in order to meet the demand for high-grade stock; in too high cost of high-grade stock; in the glutting of the market with low-grade stock; in financial injury to both the producer and consumer interests.

A summary of the loss from decay in saw timber in the United States is given in table 1. The figures on decay percentage, although based primarily on estimates made in 1923 by lumbermen and by State and Federal foresters for eastern species, with the same basis supplemented by actual measurements for certain western species, have proved reasonably reliable, for most of the species on which it has been possible to check the original estimates by measurements obtained since that time. For example, the original estimates placed the loss in Douglas fir at 15–20 percent and the lower figure was adopted to be conservative. Later, exact measurements on a large number of plots of felled timber of various ages placed the average loss in board foot volume at 17 percent. For a number of other species similar checks have been obtained, but based on fewer data. The figures in the present table are lower than the 1923 estimates by 1 percent each for oak and southern pine, 2 percent for gum, white and Norway pine, and lodgepole pine, 3 percent for cottonwood and aspen, 8 percent for western hemlock, and 17 percent for redwood. The percentage for cypress has been raised by 4, and for western red cedar by 5. The general trend is toward less cull, because a decreasing proportion of our merchantable timber is in old-growth stands.

TABLE 1.—*Estimated cull due to decay in the standing saw timber of the United States*

Species	Estimated cull	Species	Estimated cull
Eastern hardwoods:	*Percent*	Eastern softwoods—Continued	*Percent*
Oak	19	White and Norway pine	8
Birch, beech, and maple	21	Others	11
Red gum	13	Western softwoods:	
Chestnut	17	Douglas fir	17
Hickory	13	Ponderosa pine and Jeffrey pine	6
Cottonwood and aspen	19	Western hemlock	20
Ash	8	True firs	18
Yellow poplar	14	Redwood	13
Others	18	Western white pine and sugar pine	7
Eastern softwoods:		Western red cedar	20
Southern yellow pine	5	Lodgepole pine	8
Hemlock	18	Spruce	15
Spruce and fir	9	Others	20
Cypress	17		

This table does not include the loss in cordwood stands nor in timber too small to be merchantable in which decay has already commenced. Hardwoods, largely concentrated in the East, have a higher loss than softwoods, while in the softwoods the eastern species are considerably less decayed than the western. This is because the eastern softwoods are largely cut over, and the saw timber is much younger on the average than that in the West.

Young timber is relatively free from decay, but as the age of a stand increases, loss from decay increases steadily. This loss is offset somewhat by volume growth of the trees which is rapid in

youth but slows down at about the same time as decay is accelerating. Finally, a point is reached in highly defective stands at which volume of decayed wood increases more rapidly than volume of sound wood, and the stand suffers an increasing net loss year by year. This condition is shown in figure 1 for white fir in California where between the ages of 280 and 300 years, loss from decay offsets the amount of new wood added to the tree. For Douglas fir in western Oregon and Washington on good sites, loss from decay at 100 years on the average is 1 percent, at 200 years 8 percent, at 300 years 18 percent and at 400 years 36 percent; at 300 years the volume increase in decay equals the volume increase in sound wood, and from that age on stands suffer an increasing net loss. These two examples serve to illustrate the general principle, but so far investigations have made this information available wholly or in part for only a few species,

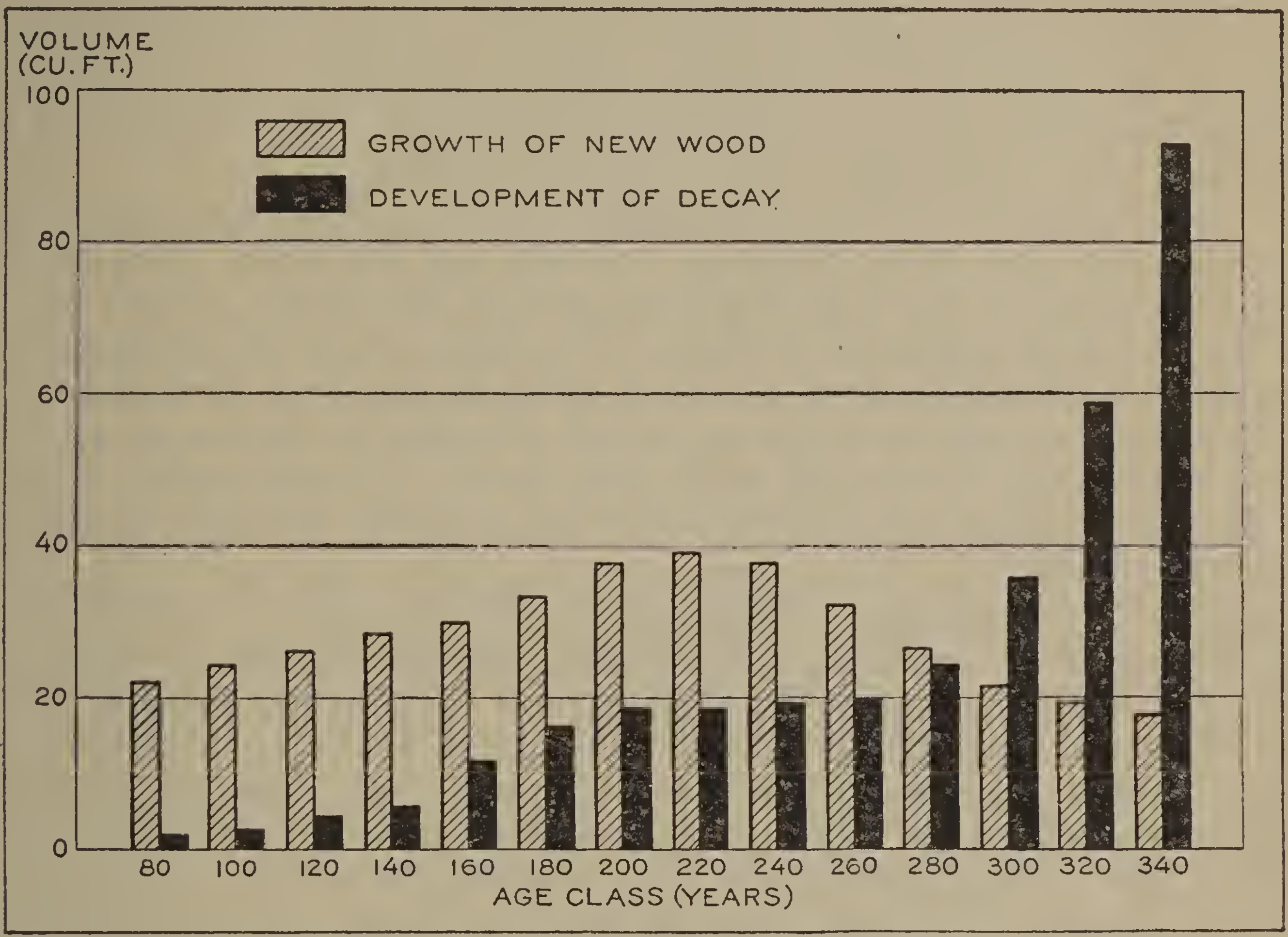

FIGURE 1.—Rate of increment of decay in white fir (California). Through youth and middle age the growth of new wood is much more rapid than the development of decay. Above the age of 280 years the increase in decayed wood exceeds the total increase in tree volume for the same period.

notably western white pine in northern Idaho, quaking aspen in Utah and Minnesota, and incense cedar in California, in addition to white fir and Douglas fir previously discussed.

The fact that decay increases with age of stands makes the method for prevention of serious losses obvious; that is, determine the age for each species at which decay becomes of economic importance, and cut the trees before this age is reached. In addition, in order to intelligently handle the overmature, highly defective stands now existing with the minimum loss, it is necessary to know the rate of decay at different ages for the component species, so that those stands in which the most rapid loss is occurring can be first harvested where possible. Then, too, it is necessary to understand the outward indications of decay in standing timber, so that timber estimating may be placed on a more exact basis, since logging operations are based on the amount

of timber that can be obtained from a given unit of area as determined by estimate. If decay is underestimated in a highly defective stand, the amount of timber obtained may be so much less than expected that it is not possible to make a profit on the operation, since more milling and logging equipment would be set up than the volume of timber warrants. Again a knowledge of the outward indications of decay makes possible more intelligent utilization of standing timber. For example, in the Douglas fir region, it is now possible to judge the amount of decay in individual trees with considerable accuracy, so that felling and bucking charges on them are avoided.

In forecasting losses from decay in timber stands of the future it is reasonable to presume that utilization will not only be at earlier ages than at present but that it will be closer. At current levels of value and with lumber as the chief product a considerable amount of sound wood adjacent to decay has to be sacrificed because its salvage cannot be made to pay. There is reason to believe that in the future not only will wood values increase to some extent but that a larger proportion of the cut may go into cellulose, alcohol, or other derived products in which closer utilization is possible. The loss in cull due to decay may therefore be expected to be lower.

In many species, decay commonly enters the tree through open wounds, and the most common wounds are fire scars. Decay then first destroys the wood in the basal part of the trunk, which is commonly the most valuable portion of the tree. In small trees the only saw timber of satisfactory grade is often in the first 16-foot log. In eastern hardwoods most decay, which frequently begins at an early age, is directly connected with fire scars. Consequently in most forest regions adequate fire protection is a valuable method of reducing losses from decay.

From the foregoing, it might be concluded that by sanitation in connection with thinning and logging operations, by utilizing the trees at younger ages and by improved methods, and by better control of fire, the disease losses in the forests of the future should be less than in the virgin stands which have been our principal source of forest products in the past. For two reasons it is impossible to take this expectation at its face value. In the first place, the desirable practices just mentioned are not being applied to most of our stands. Only a small part of our forest area is really under management, and under present economic conditions most of it cannot profitably be put under any but the most superficial management. Much of our second growth has been more fire scarred than was the virgin forest, and in addition has been subjected to undue mechanical wounding during the logging process. Instead of aiding in sanitation of forests, the bulk of our logging operations have removed the best timber and left the worst infected trees in the woods. In the second place, though we call them natural forests the stands that are coming back on old fields and cut-over land are developing under conditions that are in many ways abnormal. While their health prospects are better than for plantations, the soil conditions, stand density, and species mixture may be quite different in young natural forests from those developed under truly natural conditions. Whatever the reason, there appears in some cases to be more disease damage in second growth than is found in trees of the same age in virgin forest. It is probable that future timber crops as a whole will suffer less cull because of heart

rots than did the original stands. For other types of disease it would be altogether unsafe to predict any diminution in damage and it is entirely possible that our new forests will be considerably less healthy in some respects than the old ones.

RELATION OF FOREST DISEASES TO RECREATIONAL USE AND WATERSHED PROTECTION

The foregoing discussion of diseases has been limited to forests as sources of wood. Two other uses of forest land of increasing importance are for recreation and for watershed protection. The pathological problems connected with these uses differ in a number of respects from the problems connected with the growing of timber. High elevation forests and forested areas near cities, often low in timber-producing capacity and growing under quite different conditions from those in the best timber stands, are among the most valuable for these other purposes. There is an increasing number of forest areas that are set aside for municipal water supply, or as national, State or local parks entirely for recreation, in which the standards for judging diseases and the practices that influence them are very different from those previously considered.

The effect of native diseases on watershed protection is apparently slight. So far as our present knowledge goes, native diseases do not materially lower the efficiency of forest cover either in delaying run-off of water or in preventing erosion. It is altogether probable that in some places, particularly in the drier parts of the country, diseases do reduce the production of litter sufficiently to lessen the water-absorbing capacity of the forest floor; or that they operate to keep the finer roots from occupying and holding the surface soil to the normal extent. Such effects are not conspicuous and careful experiments continued through a period of years, too expensive to be justified under present conditions, would be needed to determine their importance.

The relation of forest pathology to recreational use is not so simple. It is true that there is no obvious way in which ordinary diseases impair the value of the forest for game purposes. In areas used primarily for recreation, tree diseases, generally speaking, are of importance only when they detract from the beauty of the landscape or upset the natural balance of plant associations which should be maintained so far as possible. Heart rots and growth-reducing diseases that might make the difference between profit and loss in a timber-growing project have much less effect on aesthetic values; in fact to some people, hollow trunks and gnarly or irregular crowns make trees more picturesque. However, killing diseases often materially hurt the appearance of the forest. Trunk and butt rots predispose to windbreak and windthrow and such trees are dangerous in the immediate vicinity of roads, trails, and camps. Diseases which cause a conspicuous amount of unsightly yellow and brown dying foliage are sometimes very objectionable.

Incongruous though it may seem, the genus Homo, for whose pleasure these tracts have been set aside, continues to be the chief menace to their beauty and permanence, and many areas, especially in the vicinity of hotels, camp and picnic grounds, have already been damaged to such an extent as to impair their value for decades, if not for all time. Continual trampling of feet and frequent building

of camp fires completely remove the surface humus which provides organic matter for the underlying soil and causes pronounced compacting, thus creating such unfavorable conditions for plant growth that many fine big trees, often several centuries old, are killed directly or by root fungi or other parasites that take advantage of these adverse conditions. Constant and indiscriminate use of automobiles in such areas leads to mechanical wounding of many trees and to soil poisoning by dripping of oil and gasoline. More must be known particularly as to the way in which campers and tourists affect diseases by changing soil conditions. The loss of two or three dominating trees on a camp ground may cause more real reduction in value than the killing of as many acres of remote timberland. Intelligent location and planning of sites for this intensive use and more adequate supervision of their occupancy will be essential to prevent damage.

DETERIORATION OF KILLED TIMBER

Occasionally there are extensive stands of mature timber that have been killed by such agents as fire, insects, windthrow, and more rarely introduced parasitic fungi. Killed timber rapidly deteriorates from checking, staining, wood-boring insects, and decay, the rate of deterioration varying with the tree species involved. Prompt removal and utilization of such timber is the only effective method of salvage. This is not always possible either because of economic conditions or because the aggregate volume killed while large is so scattered that it cannot possibly be salvaged at a profit. Where bark beetles have done the killing, stain fungi that entered with the beetles are already established in parts of the sapwood by the time the trees died.

In 1921 more than 3.5 billion board feet of very large merchantable timber of high quality was windthrown on the Olympic Peninsula in Washington. At the end of the first season of exposure the loss in Douglas fir amounted to 1 percent, in Sitka spruce to 3 percent, and in western hemlock to 13 percent. By the end of the sixth season the losses were 19, 36, and 78 percent, respectively. From the fourth season on, most of the loss was caused by decay, and during the first three seasons by blue-staining fungi and wood-boring insects.

Balsam fir killed by the spruce bud worm in northern Minnesota and Wisconsin is so quickly decayed that stands are not worth salvaging after the third year of exposure.

Chestnut presents the most important problem in timber salvage which has ever faced the United States. The chestnut blight is responsible for the death of millions of acres of chestnut timber from Maine to Alabama. In New England and the Middle Atlantic States where the disease first struck, fair prices simplified the marketing problem. In the southern Appalachians, where the menace was not appreciated by timber owners until after the World War, a glutted lumber market accompanied by ridiculously low prices has made utilization difficult.

Fortunately chestnut heartwood is unusually durable; investigations have shown that the tannin content is not materially less in trees dead 20 to 30 years than in living trees. For the first 10 years after a tree is killed by the blight, the loss in wood volume from decay is not important. After that time, windthrow increases markedly and the down trees deteriorate at a much more rapid rate than those left standing.

While in time the extract industry can very likely utilize a considerable part of the killed southern chestnut, every effort should be made to promote its immediate use for other purposes for which it is suited.

Reports from some New England pole-using companies indicate that the average service life of untreated chestnut poles set in recent years from local cuttings is materially shorter than that formerly secured. Whether this is due to the use of blight-killed poles which have been standing dead in the woods for some years before use, the increased prevalence of chestnut heartwood decaying fungi or some other factor is unknown.

DETERIORATION OF FOREST PRODUCTS

Fungi, microscopic plants which include in their number the principal causes of disease in forest trees, are also the most important causes of deterioration of forest products.[2] The fungi attacking forest products belong to two distinct groups. The stain and mold organisms consume the contents of the wood cells with relatively little damage to their structure or strength, the losses they cause being due to the discolorations that result. The decay fungi by attacking the cell-wall material weaken and ultimately soften the wood, or may even completely destroy it. Both groups are able to grow only in wood that is moist but not water-logged. The less important discoloring fungi will be considered first.

STAIN AND MOLD

The fungi that cause both of these defects are practically limited to the sapwood. The slender filaments of the stain fungi that penetrate the wood give it a permanently darker color, commonly bluish in cast, and therefore often referred to as blue stain. The mold fungi are related organisms that happen to have colorless filaments so that only their surface growth is visible, and all signs of their presence disappear if the wood is planed. Therefore, while molds interfere with sales of certain kinds of material, they are less important than stain. Stain decreases the marketability of wood for most purposes and in pine it throws lumber down into the lower grades which bring a price less than the cost of production. Sap stain thus aggravates the glut in the market for the very lowest grades of lumber. It affects the drain on timber resources by increasing the tendency to overcut the forest in meeting the demand for the higher grades of lumber. This in turn results in a still further oversupply of the lower grades, and a still greater difference in prices between upper and lower grades. Pine and gum are most susceptible to damage, and wood from second-growth stands is more affected because of the higher proportion of sapwood. For both of these reasons the sap-stain damage is greater in the East than in the West. In pulpwood it is also something of a factor, making necessary stronger bleaching treatment in paper manufacture. The overcut to replace high-grade material that has been reduced in grade by the staining fungi has never been estimated on a quantitative basis;

[2] Insects as agents in the deterioration of forest products are considered in the section entitled, "Progress of Forest Entomology."

it is much less than the overcut due to decay, but since it is in material that can be derived only from saw timber, it is a considerable element in forest depletion.

Most loss from sap stain occurs in saw logs that are delayed in getting to the mill, and in lumber during the first few days after seasoning. Log stain has proven very difficult to avoid when conditions prevent prompt milling. Surface spraying treatments have proven experimentally successful for protection during the ordinary log-banking season in the South, and are about to be tried on a large scale. For lumber that has not been stained in the log, kiln-drying is an excellent preventive, but is in use only in the higher grades and at the larger mills. A promising recent development obtained by the Department with the cooperation and financial assistance of southern lumbermen is the discovery of inexpensive antiseptic dips more efficient than any previously known, effective on hardwoods as well as on pine, and practicable for use by small as well as large mills. These are already in extensive use, but further experiments are needed to firmly establish the procedure. With perfection of the details of the treatment, and adequate educational work among the small operators, both on the antiseptic treatment and the general handling practices that decrease stain hazard, it is believed that the financial loss and excessive drain due to sap stain will be very materially decreased. Foreign customers are particularly insistent on wood that is free from stain, and exports of southern lumber have already been favorably affected as a result of the improved appearance of the treated wood.

LOSS FROM DECAY

The principal loss in wood volume due to decay of forest products is in logs banked in the woods or at the sawmill, lumber and sawn timbers in seasoning or storage piles or in exposed construction, fuel wood and pulpwood in storage, and ties, fence posts, and mine timbers in storage and use. The proportion of lumber and fuel wood lost by decay is not high, but because of the very large volume of these items, they supply an important part of the total decay loss. The losses in ties, posts, and mine timber are large because of the moist conditions under which they are used. Poles and piling are also used under conditions that favor decay, but because of the relatively small volume of use for these purposes their effect on the total loss is much less. Decay losses necessitate the cutting of additional timber for replacement purposes. It is estimated that the overcut necessary to replace decay losses in all classes of forest products amounts to more than 10 percent of the total cut. For products derived from saw timber, the estimated overcut required for decay replacements is approximately 9 percent of the saw timber cut, which is a smaller figure but more significant not only because of the greater value of saw timber but because of the slow rate at which losses of saw timber are replaced by growth. On the basis of 1925–29 production, the decay replacement estimate for saw timber is found to equal half of the estimated current growth for this class of material.

The consequences of decay to both producer and consumer of wood and wood products are out of proportion to the value of the material destroyed. Production costs are increased by storage and transit losses. The higher costs hamper the lumberman in competition with

producers of wood substitutes and impose a hardship on the consumer. The replacement of wood that is damaged by fungi after it is put in service entails labor and other incidental costs that total much more than the price of the wood used for the replacement. Costs of replacement material cannot be exactly determined, because the losses occur at different stages between felling in the woods and use in buildings, fence lines, etc. Making rough allowances for this fact, as well as for the labor costs of making replacements, it appears that on the basis of the production and prices of the years 1925–29 annual costs of replacements because of decay averaged more than a quarter of a billion dollars, and were thus more than half as great as the annual fire losses reported by the Board of Underwriters for the same period. Furthermore, particularly in the case of house construction, the uncertainty element due to sporadic and spectacular cases of destruction by dry rot causes builders to turn to the use of wood substitutes to an extent greater than the average damage would warrant, with unnecessary losses in economy and often in utility. Decay in forest products, therefore, causes immediate loss to industry and to the public, as well as ultimate loss to the country from the resultant overcutting of the forest and depletion of an important natural resource.

In comparing the losses due to fungous deterioration of forest products with the losses due to diseases of the living forest, it is probable that the products losses are less serious as a cause of depletion of timber resources. When, however, the immediate financial effect is considered, it appears that the damage to forest products exceeds forest diseases in importance. This is due to two factors: The wood in the form of forest products is worth several times as much as the stumpage of the timber from which it came; and the heavy costs in other items incidental to replacements further raise the total damage figure.

PREVENTION OF DECAY

A large wood-preservation industry has arisen within the last 40 years, and particularly by its accomplishments in tie preservation it has made a notable contribution to the conservation of timber resources. There is still need for improvement in methods of preservation and for its extension to a larger proportion of the material used. Too little progress has been made in the preservation of wood that is to be painted or stained, or used in dwellings. In most parts of the country it is difficult or even impossible for the small consumer to get treated lumber. Current treating methods are expensive, and some of them are suspected of making the treated wood dangerous to the users. Particularly in the South and on the Pacific coast, the destructive dry-rot fungi establish themselves in new buildings and cause extensive damage which, in some cases, proves very difficult to stop unless treated wood is available for critical parts of the structure.

There is also room for material improvement in other practices as well as in wood preservation. Prompt utilization or the seasoning of green material, subsequent protection from the moisture that decay fungi must have in order to attack the wood, and sanitation in lumber yards are practices which help to prevent decay, but they are often ignored and in many cases it is impracticable to follow them. Research needs to be extended both in the direction of field trials for the

simplification of protection methods based on principles already discovered in the laboratory and in the direction of further fundamental research without which entirely satisfactory field methods can never be developed. Both the present information and that later developed need to be made more readily available to the smaller wood producers and wood users by service and demonstration work.

OUTLOOK

Among the factors tending to increase damage by fungi to forest products are the increasing volume of small-mill lumbering, use of less durable species and of a higher proportion of sapwood, and the architectural trend toward low foundations. However, practicable improvements in seasoning and preservative processes and in building practices, and the increased use of treated wood or of wood substitutes in situations of high-decay hazard, should more than counteract the unfavorable factors and result in some net decrease in decay damage, as well as in decided decrease in the losses from sap stain. The possibilities in the way of preventing fungous damage are much greater in forest products than in forest trees. The products losses have already been reduced far below those that would occur without active control procedure. It would be technically possible to develop practices that would prevent practically all loss; it is doubtful, however, if the reduction in fungous damage in the next 20 years will be any more rapid than the reduction that is expected in forest growth. Increased protection against fungous attack will take place concurrently with advance in three processes: Research aimed at the cheapening and simplification of protective methods, education of wood users as to improved practice, and increase in lumber prices which will increase the number of types of use in which protection is cheaper than replacement.

Further consideration of the pathology and protection of forest products will be found in the section entitled "Enlarging the Consumption of Forest Products."

FOREST DETERIORATION BY INTRODUCED DISEASES

In the foregoing nothing has been said of the dangers of serious and widespread epidemics. Native fungi, or fungi that have been introduced in the remote past and to which our forests have already become adjusted are not likely to cause catastrophic epidemics in native tree species or threaten the extermination of any commercial forest tree. The introduced disease, on the other hand, is a potential danger to the commercial existence of every one of our commercially important timber species.

The history of agriculture and horticulture in this country prior to the passage of the Plant Quarantine Act of 1912 and to the issue of the general nursery stock importation restrictions in 1919 was a procession of invasions by both plant diseases and insect pests from abroad. Wheat, potato, cotton, corn, asparagus, and peach are among the important crop plants that have suffered from foreign attack at one time or another in our history. Most of the attacks have been met by the quick substitution of resistant varieties, by a shift of the center of cultivation from one part of the country to

another, by changes in methods of cultivation, or by expensive methods of direct control, such as spraying the plants. None of these procedures are possible in forests. The ultimate result in agriculture has been more complicated methods of production and increased cost to the consumer. In forests similar invasions of virulent pests are likely to mean the loss of valuable tree species and permanent reduction in forest values.

As the result of the unfortunate experiences which we have already had, the impression has developed in certain quarters that any foreign fungus will do more damage than a native fungus of the same type. This impression is incorrect. Most foreign fungi when transferred to a new habitat find that the climate or the lack of the food materials to which they are accustomed makes it difficult for them to exist in competition with the better adapted native organisms. However, a foreign fungus which does find among our tree species one which is a congenial host may do to it exactly what the blight has done to our chestnut, or at least may injure it more than any native fungus could possibly do, because to the foreign fungus the tree lacks the specific resistance which in past ages it has acquired to the native parasites.

A foreign fungus may attack in a less conspicuous manner than the chestnut blight and develop more slowly but nevertheless to a sufficient degree to ultimately take most of the profit from the management of the host species. It often happens that the introduced disease is not at first recognized as such. A number of the diseases that are now causing concern in the United States are under the suspicion of having been introduced, but if they have been introduced it was so long ago that their history cannot be determined with certainty. Among those that are known or suspected to have been originally introduced are enough different types to illustrate most of the kinds of damage that we have to fear from diseases from other countries.

The one that first occurs to the minds of everyone familiar with eastern forests is chestnut blight, an importation from Asia. In a period of approximately 40 years since its probable time of entrance is has destroyed one of our half dozen most important hardwood species through the northern two thirds of its range. There is still available a large volume of chestnut saw timber in the southern Appalachians and more widespread utilization of this chestnut lumber would assist in conserving our limited stands of other eastern hardwoods. But this southern Appalachian chestnut region is now infected with the blight, which is rapidly advancing and will in time eliminate the American chestnut as a commercial tree. Chestnut, because of its excellent growth even on the poorer soils, its ease of management, the value of its nuts, the high durability of its wood, and consequent usefulness for a number of purposes, was perhaps the most valuable single species of all our hardwoods. It still furnishes over half of our domestic tanning materials, and has the unique feature that the tannic acid is taken from wood which is not wasted but can then be converted into paper. No satisfactory domestic substitute for chestnut tannin has been found. Fortunately chestnut can be used for tannin production for 20 or more years after the trees are dead. Other species have promptly replaced the chestnut

on the better sites; we therefore have not extended our idle land or had any serious watershed problems as a result of this unprecedented epidemic, but much of the land on which the chestnut formerly predominated is permanently reduced in commercial value as a result of the change to less profitable species. This loss of productiveness of the former chestnut land is an even more serious matter than the immediate loss of the merchantable chestnut stands.

Where the disease has run its course and killed practically all the trees, the causal fungus has decreased in abundance locally for lack of food material, in some places to an extent sufficient to permit the new sprouts to attain a considerable size and even to bear nuts before becoming infected. In the cases that have been kept under observation for a sufficient length of time the evidence is that these new trees are susceptible. Despite much search by both governmental and private agencies, no native trees that have been tested so far have shown enough resistance to enable them to produce merchantable stands in the presence of the disease. During the past 20 years large numbers of promising trees and sprouts which continued for a while to develop in the presence of the blight have finally succumbed. Trees and sprouts in 200 different localities in 18 States are still under observation by the owners in cooperation with the Department to determine if they really are resistant. While it is to be hoped that some individual native trees may yet be found so nearly immune that they can be used as propagating stock for the replanting of the American chestnut, the statements recently given prominence in the public press that the chestnut is coming back, are, to say the least, premature. Strenuous efforts are being made to find Asiatic chestnuts that will be resistant both to blight and to American parasites, or to produce hybrids with the American chestnut that will serve the same purpose. These efforts may ultimately give us as good a tree as the one we have lost; but any such result must require many years of work, and if actual reestablishment of all the chestnut forests prove practicable, it will require generations to accomplish it.

The white pine blister rust, perhaps as well known as the chestnut blight, stands in quite a different category from the chestnut disease. It was introduced to this country from Europe, though it may have come originally to that continent from Asia. In the eastern United States it works more slowly than the chestnut blight, but is nevertheless an unusually conspicuous disease and was recognized at a relatively early stage in its American development. One weak point in its life history, namely, its need for a currant or gooseberry bush as an alternate host, has made it possible to evolve a method of protecting our most valuable northern white pine stands before it had time to cause great injury. Reproduction has been considerably reduced in some places in the Northeast and in the Lake States, but the control campaign has in general safeguarded us against heavy losses in merchantable stands and promises to make it possible to continue the growth of white pine in most of its original commercial range. The only places in the main commercial range where the northern white pine may be forced out as a commercial species are some in which the cost of eradication of the currants and gooseberries is excessively high or where attack by other diseases and insects makes the species too difficult to maintain when the added costs of blister-

rust control are considered. A dying out of the species is to be expected in the marginal portions of the range, where its representation in the stand is not heavy enough to justify control measures. On the other hand, in some of the outlying sections where the alternate hosts can be cheaply eradicated and growth rate and markets are favorable to the pine, it is probable that white pine production in the future will be greatly increased through planting. In the major portions of the range in which protection is practicable, the cost per acre of the protection ranges from 5 cents to $2 per acre, with an average of 44 cents. This figure covers all charges—Government, State, and local, as well as the actual cost of removing the bushes. In most places eradication of alternate hosts is advisable at about 5-year intervals, but the cost of these later eradications is less than that of the initial one.

The status of the blister rust in the West is less hopeful. Western white pine and sugar pine are still more susceptible than the northern white pine, and the currants and gooseberries that act as alternate hosts in the West are more numerous, more congenial to the rust, and more difficult to eradicate. Both the infection and the control campaign in the West are relatively recent, and the proportion of the stand of these two important western timber species which can be protected from rust at a practicable cost in the present profitless state of the local lumber industry remains to be determined. It is feared that most of the privately owned white pine stands of Idaho will be destroyed because of the inability of the owners to finance control.

Both the chestnut blight and the blister rust, where allowed to run unchecked, affect the æsthetic and thus the recreational value of the forest to an extent not encountered with most native diseases. So many trees are killed at once that it takes many years to replace the skeletons of the killed trees with enough trees of other species to restore the beauty of the forest. To a great many people the species which replace them are decidedly inferior in beauty to the chestnut with its remarkable spreading branches or to the white pine with its dark masses of foliage.

In the case of chestnut blight, the wholesale killing of the trees on thin soils on upper slopes in places in Pennsylvania has in some cases resulted in soil deterioration through opening up of the stand to such an extent that the humus layer has disappeared and centuries may be required to restore the original value of the watershed.

Even where a lost timber species is replaced promptly and completely by others of equal commercial and aesthetic value, there is chance for indirect and deferred damage to the forest. Most of our forests are balanced associations of a number of species of trees and shrubs, and the soil organic matter is largely controlled by the species mixture. There are numerous ways in which these species can affect each other, and the complete removal of any of the commoner species may result in soil changes unfavorable for the entire association, or in otherwise so unbalancing the forest-tree community as to seriously reduce its productiveness.

The other introduced diseases of our time appear thus far to be less serious because they are less active, because they are attacking trees of less economic importance, or because they have been introduced in localities where the most susceptible native tree species are not com-

mon. One which appears particularly virulent is the willow blight, caused by a leaf and a twig fungus working in partnership, both of them introduced. This disease in the willows of the Northeast has made a record for quick killing. It is destructive in this region on several native willow species. If in its spread over the country it is found to be equally virulent in regions farther south and west, or if forestry developes further in the direction of cellulose production so that willow can become important for wood production in bottom lands, this disease may yet prove very serious. The willow is the one tree best adapted to the holding of the soil on the banks of streams in some parts of the country, particularly in the Middle West. It is impossible to predict to what extent flood-control problems might be aggravated by the loss of the willows. There is no prospect of direct control for this willow disease, but there is an unusual chance for the substitution of resistant willow species or of resistant varieties of susceptible species for the willows that are destroyed. The short generations and easy vegetative propagation of the willow greatly facilitate breeding of resistant varieties.

The larch canker illustrates a very different type of a recent importation. This larch disease has long been troublesome in European forests. It was brought to this country on imported stock from Scotland a score of years ago. Because of the small amount of larch in the locality where it was introduced, it spread slowly, and since its discovery the entire eradication of the known cases has apparently been successful. So far as known it no longer exists in this country, but some years of follow-up work and more extensive reconnaissance are necessary before it will be safe to say that the fungus has not succeeded in establishing itself anywhere in our native larch. Had the disease been introduced originally into a region containing much larch, the story of this introduced disease would have less chance of having a happy ending.

The so-called Dutch elm disease which was apparently introduced into Europe has done tremendous damage in the elms of the low countries and has now extended into the British Isles and through Middle Europe. It has been found recently in Ohio; but in spite of the most energetic search, in which the cooperation of the public and the commercial tree surgeons has been enlisted, it has been discovered to date on but eight trees. Wherever found it has been eradicated. While the American elm is known to be highly susceptible, we have reason to hope that the disease is not yet present elsewhere in the country or that conditions in this country, as for example the absence of one of the insects which appears to aid in its spread, will prevent its active operation in our elm species. The loss of the elm would, of course, reduce our timber resources in certain locations and for certain purposes, and make a tremendous inroad on our tree resources from the æsthetic standpoint in the North and East; in New England it is more important as a street tree than all other species together.

One of the most recent attacks of a possibly introduced disease is affecting the two most important pines of the northeastern States. Both northern white and Norway pine are being killed by a resinosis at the base of the trunk in three New York plantations. If not distributed on nursery stock, this disease will probably be unable to spread rapidly. However, in forests it is obvious that a slow but sure spread can ultimately be quite as serious as a more rapid spread.

This new disease has been under study by the New York authorities for three seasons, but because of the complications entering into root-disease investigation it may be several more seasons before we can be certain of its antecedents or just what may be expected of it in the country as a whole. This illustrates one of the weaknesses in our preparedness against introduced diseases. We are yet so little acquainted with the native diseases of our 180 commercial timber species that when a previously unobserved diseased condition is found it is often difficult to decide whether it is native or introduced.

The newest threat is to the beech. A bark fungus of unknown source has joined with a scale insect to destroy 40 percent of the beech of Nova Scotia. Infection has now appeared in Maine, where it is still very limited but is spreading with alarming speed.

Serious as some of the foregoing cases are, there is some reason to think that we have scarcely begun to suffer from introduced diseases. To lose a single species from among our numerous forest trees is not a complete disaster but to lose several from the same region might very seriously cripple forestry both from the timber production and the recreational standpoint. It is very probable that we already have a large proportion of the dangerous fungi that were native to Europe. Up to 1912 the United States Government had no legal authority to exclude diseased propagating stock, and it was only after the quarantine regulations of 1919 that the policy of free trade in plant diseases really came to an end. However, considering the great number of forest species related to ours which are found in Asia, and the relatively small amount of commerce which we have had with Asia, Africa, and South America until recent years, it is probable that we have thus far been exposed to relatively few of the potential tree-disease organisms of those continents.

Diseases brought in before 1919 may yet remain to be discovered. A single importation of a disease, even if it be a virulent one, seldom spreads far enough to be discovered or brought to the attention of our small staff of forest pathologists until it has been in the country at least 10 or 15 years. While the quarantine regulations now in force have undoubtedly prevented or greatly delayed the introduction of pests since 1919, no system of quarantine which it is possible to enforce at present can guarantee absolute exclusion of new diseases indefinitely. Yet every delay in introduction is vastly important, not only because it avoids damage or costly readjustment to the intruder but also because we are likely to be able to meet the newcomer in the future with a more organized and efficient effort than can now be directed against it. Complete enforcement is impossible, and quarantines cannot be applied to some kinds of imports without excessive interference with commerce. For example, it appears impracticable to limit the importation of wood in the form of logs, pulpwood, or packing cases, though there is considerable possibility that these imports may bring with them tree diseases of the vascular-wilt type exemplified by the maple wilt and the so-called Dutch elm disease, as well as fungi that will add to our deterioration problems in forest products. Few introduced organisms would be as easy to control as the blister rust. From the nature of the case, any prediction is highly speculative, but the probabilities favor trouble from now unknown foreign diseases for others of our important tree species.

The introduction of dangerous organisms is not limited to the bringing in of new species. It is now well known that our most important fungous species consist of numerous strains, some of which differ from others very clearly in their virulence. For example, the well known root-rot fungus *Fomes annosus* is common throughout both Europe and North America. In the Douglas fir in the Pacific Northwest it is very frequently found, but appears to be unimportant so far as parasitic activity is concerned. In Europe, on the other hand, it is an extremely serious parasite in planted forests and causes heavy damage to European plantations of our own Douglas fir. There is reason to believe that some of the European strains of this root-rot fungus are more dangerous than any of those which we now have; their importation might prove serious, particularly for our reforestation projects.

Introduced diseases must be found, studied, and if possible eradicated while they are new in this country. Delay may mean their escape beyond control. To permit infectious material to remain undisturbed for study in our forests or among shade trees is manifestly unsafe. The knowledge of the disease, its methods of spread, and the vulnerable points in the life history of the causal organism, essential for effective eradication, can be acquired safely only by studies abroad in the countries where the disease is already established and these studies need to be carried on at the earliest possible moment after the discovery of a disease in America. In the cases of virulent diseases known to exist abroad and to be able to attack trees related to our forest species, but which have not yet gained entry into America, it is the part of wisdom to conduct preliminary studies in the foreign countries to get information that will enable us to prevent or at least to delay as long as possible their introduction here. The Dutch elm disease is an example of a case in which studies abroad are needed. At the present moment no one can answer the question, How did the elm fungus reach America? We cannot know just how to quarantine or where to expect additional outbreaks and combat them intelligently and effectively till this question is answered.

Troublesome diseases may be introduced from other parts of our own country as well as from abroad. While it is possible that most of the dangerous fungi native to this country are already present in every part of the continental United States in which there is any common native host that is particularly susceptible to them, this is by no means certain. A fungus living harmlessly on the outer bark of eastern hard pines has been proven able to cause severe damage to Douglas fir in the East. This tree in its natural range would probably be more resistant to the fungus; but if the fungus should reach the western forests and should there prove able to attack this most important species as it does in the East, we would have a forest calamity. An example of danger from the movement of native diseases in the opposite direction is afforded by the dwarf mistletoes of pine. Probably the most important of the growth-reducing parasites, they are now limited to the West, and are separated from the eastern pine stands by a belt of prairie hundreds of miles wide along the hundredth meridian. These mistletoes are not spread by the wind as are the fungi and can establish themselves in a new place only if both sexes are introduced. It is probable that the eastern conifers have never been exposed to them. Artificial inoculation experiments in neutral

territory have shown that some of these mistletoes can attack eastern species and it is possible that if introduced to the East they would be found to be serious enemies of certain of our eastern pines. One fungus of uncertain origin which was perhaps brought from the West to the East is the so-called "Woodgate rust" occurring on Scotch pine in New York State. Injury by this disease to our valuable southern slash pine is feared if it spreads to the South.

To summarize: Introduced diseases now in this country cause less damage than is done collectively by our many native diseases, but there is reason to fear that unless quarantine is fully supported and proves highly successful, we have only seen the beginning of the introduction of acute diseases of foreign origin. Our forests may be exposed at any time to new epidemics, with consequent commercial loss of additional native timber species. While even the most serious of the native diseases limit their effect mainly to reducing the yield of forest products, the introduced epidemic disease may also cause serious loss in aesthetic and recreational value of the forest, and in some cases may diminish its value in watershed or stream-bank protection. The agencies engaged in protection against foreign diseases are handicapped by the lack of knowledge of the tree diseases in foreign countries, and their methods of dissemination which makes it difficult to establish fully efficient quarantine regulations; this same ignorance together with the insufficient knowledge of native diseases makes it difficult to recognize a new disease promptly after it gets into the country. When all things are considered, it is by no means impossible that by the end of the present century our forestry program may be more hampered by new diseases from abroad than by all of our native diseases. Movement across the country of native diseases now limited either to the East or to the West, though less dangerous than the introduction of foreign diseases, is also a basis for some concern.

PRESENT STATUS OF RESEARCH AND CONTROL

AGENCIES ACTIVE

Considering the immense area of land in this country suitable only for tree growing and the part that timber produced on this land has played and must continue to play in the economy of the Nation, the agencies engaged in developing principles for the control of forest-tree diseases are inadequate.

Federal work on forest-tree diseases is carried on in the Bureau of Plant Industry, Department of Agriculture, by the Division of Forest Pathology and the Division of Blister Rust Control. The Division of Forest Pathology is purely an investigative organization to develop principles for the control of tree diseases. In addition to the central organization in Washington, this Division maintains one or more pathologists in 3 of the 9 regional offices and 3 of the 11 Forest Experiment Stations of the Forest Service. After principles of control have been determined, their actual application on national forests is carried out by the administrative officers of the Forest Service supplemented by whatever assistance in instruction or supervision is needed from the Division of Forest Pathology to make the work effective. The same assistance is given on other Federal forest land, on State forests,

and to a lesser extent on private forests when needed. As the result of a small appropriation for that purpose, the Division is now aiding the National Park Service by making a special reconnaissance study of tree diseases in the national parks and advising methods of control. The Division also maintains pathologists with the forest products laboratory for special work on diseases affecting forest products. A limited amount of study of dangerous foreign or introduced diseases has been made in the countries of origin, to secure information of value in planning quarantines and eradication work.

The Division of Blister Rust Control applies and extends measures for the control of white pine blister rust, based on principles established for it by previous research by the Division of Forest Pathology. Through cooperative agreements, the Division of Blister Rust Control maintains an organization in all States which have commercially valuable stands of white pine. This organization supervises the control of blister rust on State and private lands. The same assistance is extended to Federal land.

Aside from control of blister rust, there is relatively little work done by individual States on forest-tree diseases. New York conducts some pathological work in its conservation commission for this purpose, and the Natural History Survey of Illinois is giving attention to diseases of elm in that State. In Ohio, Idaho, Pennsylvania, Minnesota, Michigan, New York, and Connecticut and a few other States there has been investigative work carried on incidentally to teaching in the State educational institutions or to research in general plant pathology in the agricultural experiment stations. The small amount of attention to forest pathology in State institutions is probably due as much or more to the inclination and training of individual pathologists and lack of available funds than to any definite policy or lack of interest of the institutions concerned. Forest diseases cannot be investigated with the ease or speed with which results can be obtained on the diseases of smaller and shorter-lived plants; and the damage and control phases of such investigations can be adequately handled only by men who have a knowledge of forestry as well as of plant pathology. These facts have induced general plant pathologists to study forest diseases only incidentally and without the continuity of effort that is absolutely essential in the study of diseases of long-lived host plants. Many States whose forests are a primary resource do no work in forest pathology.

There are no private organizations for investigation or control of forest diseases. Three endowed universities with forest pathologists on their teaching staffs do some research. The Oxford Paper Co. in cooperation with the New York Botanical Garden is studying the diseases of poplars with a view to developing resistant varieties for the use of the company. On a few private forests there is a steady and well directed effort to reduce diseases to the minimum. In the main, the private timberland owner does not realize the presence or importance of disease unless numbers of trees are killed simultaneously. Control of white-pine blister rust has been applied over extensive areas of private forest land in the Eastern States through a cooperative service organization which has proved to be unusually effective in securing general application of the results of investigative work.

CONTROL PRACTICES

Although the basic principles of control of forest-tree diseases are fundamentally the same for all stands, the application of these principles is strongly modified by the character and location of the stand and the purpose which each stand serves. The necessity and economic feasibility for control measures vary considerably on forest lands for timber production, for recreational use, and for watershed protection. In any case intelligent control must be based on investigation of individual diseases in their relation to the stand as a whole, and the many problems demanding attention are far beyond present available resources for this purpose.

Direct control of native diseases is being practiced to a considerable extent in forest nurseries. In nurseries, trees are grown so closely crowded and under such artificial conditions that they are extremely susceptible to disease, but this same occupancy of a limited area by a large amount of valuable stock makes it possible to spend relatively large sums of money for direct-control measures, such as special methods of cultivation, soil treatment with chemicals or with steam, spraying with fungicides or iron solutions and eradication of diseased plants in the immediate vicinity of the nursery. Moderately satisfactory control methods have been developed for the more conspicuous nursery diseases, and new or obscure diseases should also prove susceptible to control when sufficiently studied.

Native diseases in the forest must be largely controlled by indirect methods, such as the removal during cutting or thinning operations of diseased trees or those in a condition to be especially susceptible to disease. The expense is mainly in hand labor, so that such operations could be carried on very cheaply at the present time. So far such efforts are largely confined to certain national forests, although a few private owners are also eliminating diseased trees in thinnings and final cuttings. A clause in national-forest timber sale contracts, first introduced in 1911, calls for cutting diseased trees even though they may be mainly or entirely unmerchantable. In California where there has been the longest experience with its operation, this sanitation cutting has been found to have a number of other advantages as well as the removal of infection sources, and if any cost must be charged to the disease-prevention feature it is very slight. It has been found that most butt rot, which is an important item in decay in conifers and the principal cause of cull in hardwood saw timber, enters mainly at fire scars, with logging scars also of some importance. This means that fire control and care in logging can be regarded as factors in disease prevention. In plantations and managed forests, disease prevalence can undoubtedly be controlled to some extent by controlling stand density. Unfortunately, information on the relation of density to disease has been determined for only a few diseases, so that wide application of this principle will have to wait for additional knowledge. The relation is sometimes indirect; for example, a high stand density can be made to help protect certain tree species from rust fungi, because it tends to kill out other species of plants that the rusts require as alternate hosts.

Investigations by the Federal Government of wood-destroying fungi that cause heavy losses by decaying the wood of trees of merchantable size, have shown for the few species studied that young stands are practically free from decay but with increasing age, losses

become heavy. Consequently losses in present young stands are largely avoided if they are cut before they attain the age at which decay becomes economically serious. In addition, determination of outward indications of decay in living trees have enabled volume estimates of standing timber of certain species to be made more exactly, thus reducing one element of uncertainty in the lumber industry, since the investment in all logging operations is based on the amount of available timber determined by ocular estimates. Some operators on private land in the Douglas fir region of western Oregon and Washington have also used this information to leave unmerchantable decayed Douglas fir trees standing and thus save felling costs. There this practice will not cause increased decay in the future, because the new Douglas fir forests will be cut before reaching the age at which significant loss from decay begins. However, under usual conditions decayed trees should be cut along with the others to protect future stands. So far only a few important species have been studied and many more remain for future work.

When practicable, direct control measures must be applied to virulent, introduced killing diseases, since it is these diseases that may eliminate a native species as a factor in commercial timber production. The commercial extinction of chestnut, now in progress of accomplishment by the Asiatic blight fungus, cannot be stopped by any economically feasible measure; it had become too thoroughly established for successful eradication long before the systematic study of forest pathology was begun in the United States. The equally dangerous white-pine blister rust which reached this country some years later has been more successfully met. Investigation has shown that the fungus causing the disease must have two kinds of hosts for its existence—the pines, and currant or gooseberry bushes. While the disease can spread over 100 miles from pines to the alternate hosts, its effective spread from currants and gooseberries back to pines is only a few hundred yards; so that effective control is now obtained by eradicating currants and gooseberries in and around valuable pine stands. This control is being extensively applied on Federal, State, and private forest land in the East where about 9 million acres have been initially cleared of currants and gooseberries, and a beginning is being made in the West; but because of the greater difficulty and consequent increased cost of eradicating wild-currant and gooseberry bushes there and the rapidity with which the disease is spreading, the extent of stands of sugar pine and western white pine that it will be feasible to protect is still problematical.

Valuable protection against the introduction of diseases from foreign countries is given by quarantine. All forest trees and nursery plants are now excluded from the United States except for importation under special permit with provision for periodic inspection for the first few years after introduction. If a dangerous disease is known to exist on a foreign tree, it cannot be imported at all except in limited numbers by the Department of Agriculture and must then be held in a Federal quarantine house a sufficient time for any disease to develop. There is no restriction on the importation of seed, unless it is known to carry a specific disease, and no safeguards are considered practicable on the entrance of wood, either in the form of logs or in the less dangerous forms of packing cases, paper pulp, etc.,

though both seeds and wood may sometime bring in destructive foreign diseases or decay organisms. No provision exists for preventing the spread of native forest diseases from East to West or vice versa.

One of the most useful methods in meeting diseases of crop plants is the development of resistant or immune varieties. In a plant with a reproductive period as long as that of a typical forest tree, ordinary plant-breeding procedure is extremely slow. Nevertheless, there is an excellent chance to get results in a reasonable length of time in species which produce seed at an early age or in those in which vegetative propagation can be done readily and cheaply. The introduced willow scab mentioned earlier is a disease which perhaps can be met best in this way. A beginning has been made along this line with poplars for pulp production. Constructive activity against the chestnut blight is also under way in an attempt to develop resistant lines by selecting and hybridizing among the native chestnuts and a large number of Asiatic chestnut types which have been assembled for the purpose. It is obvious that even when resistant strains have been developed, they can be established only in situations where planting is economically practicable.

The constantly increasing use of forests for recreational purposes leads to new concepts of disease and its control. The difference between recreational forest areas and timber-producing areas as to standards for evaluating disease damage has already been discussed. The two types of forest differ quite as much in the needs and possibilities of control. Investigation of the needs and possibilities in the recreational areas has been barely begun, and many of the statements following are to be regarded as tentative. Virulent killing diseases need control in such areas, and protection of the 5-needled pines against the white-pine blister rust is going forward in much the same way as in the commercial forests. For most other types of disease, less attention need be paid to control in extensive stands set aside purely for recreation than in commercial stands. The fact that little or no cutting is done in recreational stands furthermore removes one of the best opportunities for forest sanitation. However, because of the unnatural conditions created by tourist use in the neighborhood of camps, hotels, and scenic attractions, and the importance of the trees in such places, there are unusual local needs for protection, and over small areas methods of prevention or control are justifiable that would be entirely too expensive to employ where timber production is the only consideration. Despite the opinion of some that the dwarf mistletoes add to the picturesqueness of the trees, the owners of recreational areas in several places in the West have undertaken special cutting-out campaigns against them. The spraying or dusting methods developed in orchard work could be employed against unsightly leaf diseases in such places.

The greatest need is for measures that will protect the forest for the campers and sightseers, against the injury that they themselves do to it. Regulations against the careless use of fire and the concentration of trampling and automobile traffic that have partially devastated some of the camping grounds and places of interest are not enough. On the basis of preliminary study of the habits and needs of the tourist, plans have been developed for the laying out of camp sites and other areas where visitors concentrate, in such a way that

the tourist will find it most convenient to park his car, build his fire, and do his walking where any damage that may result will be at a minimum. In such special cases as the giant sequoia parks of California, special measures are taken to protect the soil from the compacting that would otherwise ultimately result in the death of the absorbing roots and kill the trees. The fundamentals of tree physiology and root parasitism need further study before the best procedure can be outlined for the different situations that are encountered. In forests in which both timber production and recreation are important, a balanced program of preventive practices needs to be worked out with consideration of both kinds of use.

No disease-control measures are known to have been applied in forests maintained purely for watershed protection, except in the course of the white pine blister rust work in the Northeast, and no other disease is known at the present time to justify direct control activity in such forests.